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2 **Error Assessment in Decision-Tree Models**
3 **Applied to Vegetation Analysis**
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ABSTRACT

Methods were developed to evaluate the performance of a decision-tree model used to predict landscape-level patterns of potential forest vegetation in central New York State. The model integrated environmental databases and knowledge on distribution of vegetation. Soil and terrain decision-tree variables were derived by processing state-wide soil geographic databases and digital terrain data. Variables used as model inputs were soil parent material, soil drainage, soil acidity, slope position, slope gradient, and slope azimuth. Landscape-scale maps of potential vegetation were derived through sequential map overlay operations using a geographic information system (GIS). A verification sample of 276 field plots was analyzed to determine: (1) agreement between GIS-derived estimates of decision-tree variables and direct field measurements, (2) agreement between vegetation distributions predicted using GIS-derived estimates and using field observations, (3) effect of misclassification costs on prediction agreement, (4) influence of particular environmental variables on model predictions, and (5) misclassification rates of the decision-tree model. Results indicate that the prediction model was most sensitive to drainage and slope gradient, and that the imprecision of the input data led to a high frequency of incorrect predictions of vegetation. However, in many cases of misclassification the predicted vegetation was similar to that of the field plots so that the cost of errors was less than expected from the misclassification rate alone. Moreover, since common vegetation types were more accurately predicted than rare types, the model appears to be reasonably good at predicting vegetation for a randomly selected plot in the landscape. The error assessment methodology developed for this study provides a useful approach for determining the accuracy and sensitivity of landscape-scale environmental models, and indicates the need to develop appropriate field sampling procedures for verifying the predictions of such models.

INTRODUCTION

Formulation of environmental policy, implementation of environmental management strategies, and assessment of environmental degradation require that knowledge generated at local scale be extended to landscape scale. The spatial and temporal scales at which processes operate, observations and measurements are made, and environmental regulations are promulgated seldom match. Methods are clearly needed for extrapolating results from studies of simplified microcosms at small spatial scales to complex landscapes.

Extrapolation of knowledge of the factors influencing ecosystems requires the development of spatial databases comprised of the environmental variables determining these factors, as well as a predictive model for their effects. We will focus on potential forest vegetation in central New York State, where the driving variables include both soil and terrain properties. These variables are available or derivable from existing databases (Reybold and TeSelle, 1989; U.S. Geological Survey, 1987).

Development of models which predict the distribution of vegetation using environmental databases requires understanding of the relationship of plant community composition to edaphic and terrain factors. In central New York State, vegetation distribution patterns have been studied extensively using a combination of field measurements, land survey records and interpretation of topographic maps, soil surveys, and multi-temporal aerial photographs (Marks and Gardescu 1992; Mohler and Marks, in prep.; Seischab 1985, 1990; Smith, et al., in press). These field-based studies have permitted the development of a classification and key establishing the relationship between the distribution of potential forest vegetation types and selected edaphic and terrain factors (Mohler 1991; Mohler and Marks, in prep). These relationships form the basis for subsequent development and application of spatially-explicit, descriptive simulation models which predict vegetation distribution at landscape scale in a fashion similar to Moore, et al (1991).

A number of authors have investigated the accuracy of spatial databases, proposing various stochastic models and assessing the propagation of error through processes of GIS (Goodchild and Gopal 1989, Goodchild et. al. 1992; Heuvelink 1993). Our focus, however, is on the methodology of comparing the prediction accuracy of a decision tree model with reference data. This type of model makes predictions by a sequence of decisions based on a single variable at a time. Error in spatial databases is therefore considered as one of the several factors leading to poor prediction of the decision tree model. Specific objectives here include: (1) determination of agreement between field measurements and input variables derived from GIS, (2) assessment of prediction agreement between models using GIS data or field data as input, (3) examination of the effect of misclassification costs on prediction agreement, (4) quantification of influence of individual environmental variables on the predictive power of the decision-tree model, and (5) estimation of rates of misclassification of the predictive model. There has been extensive research on how errors in input affect predictions in ecological models (O'Neill, 1973, Gardner et al. 1980, Rossi et al. 1993, Saltelli et al. 1993). However, the focus has primarily been on process models as opposed to decision tree models, and the input data are typically continuous rather than categorical.

METHODS AND MATERIALS

Study Area Description

The study area is located in the Finger Lakes Region of central New York State, U.S.A. The area is defined by the boundaries of the Elmira 1:250,000 scale topographic quadrangle, approximately 18,000 km². The northern region of the study area is located on the Lake Ontario Plain in which land use is dominated by dairy farming. The elevation ranges from 100 to 400 meters, increasing from north to south. Average annual precipitation is 900 to 1150 mm, increasing from west to east. Local relief is nearly level to gently rolling terrain consisting of glacially-derived beach ridges, drumlins, and till plains. Soils are recently developed from mostly calcareous glacial tills, outwash, alluvial deposits, and lacustrine sediments. Natural vegetation consists of beech-maple and hemlock-northern hardwoods vegetation associations.

The southern region of the study area is located on the glaciated Allegheny Plateau in which land use is dominated by second- and third-growth deciduous and coniferous forest, conifer plantations, and some pasture and cropland associated with dairy farming. Elevation ranges from 200 to 1100 meters, with broad, steep-walled valleys and narrow ravines. Precipitation is similar to the northern portion, but the freeze-free period is shorter. Soils are derived from acidic glacial deposits, and support forest vegetation dominated by northern hardwoods, hemlock and upland oaks (Soil Conservation Service 1981).

Field Observations and Measurements

Field observations and measurements were made at selected plots within a 3400 km² portion of the study area centered on Cayuga Lake. These provided qualitative information for construction of our decision-tree model and served as a quantitative verification sample, though not all plots could be located accurately enough for use in verification. 180 relatively undisturbed stands representing the range of natural terrestrial and wetland vegetation in the region were sampled using the 0.1 ha method of Whittaker (1960). An additional 258 relevé samples were taken to balance sample density among environmental conditions. Relevés consisted of estimates of percent cover of each woody species in an approximately 0.05 ha area with additional notes on herbaceous species. Relevés were chosen by marking accessible locations representing a range of topographic conditions on maps and then visiting sites until at least 5 relevé or 0.1 ha samples had been obtained from each combination of slope gradient (3 categories), aspect (3 categories) and slope position (3 categories) in each of the northern and southern regions of the study area. Submerged aquatic vegetation, urban areas, plantations, orchards, cultivated fields and abandoned farm land were excluded from the sample. In both the 0.1 ha plots and relevé samples, slope gradient, slope aspect, slope position, and elevation were recorded. Additional data on soil parent material, pH, and drainage were obtained from soil surveys of the region (Neeley 1965, Hutton 1971, Hutton 1972, Puglia 1979).

Samples were grouped into initial vegetation types by using two-way indicator species analysis (TWINSPAN) (Hill et al. 1975), and by consulting published descriptions of ravine and swamp forests of the region (Lewin 1974, Huenneke 1982). The initial classification was then refined by using an iterative process in which samples were moved between types until the best possible match between environmental conditions and composition of vegetation was

1 approximated. This procedure resulted in 17 types (Mohler 1991), each of which is restricted to a
2 well-defined range of environmental conditions.

3
4 To estimate error rates that would occur at randomly selected plots in our study area we
5 needed estimates of the percent of the field study area in each vegetation type. These were made
6 using the descriptive vegetation-environment model of Mohler and Marks (in prep.). For
7 vegetation types which occur in only a few locations (e.g., bogs, cattail marsh), the approximate
8 area of each type was directly measured on USGS topographic maps. The remaining area was
9 divided into a northern region with calcareous soils and a southern region with acidic soils, and
10 within each region, into gorges, wetlands, steep south and west facing slopes, and other uplands.
11 Within a region, each of the topographic categories just listed corresponds to a relatively few
12 vegetation types. Three topographic maps were chosen at random from each of the two regions
13 and the area in each of the categories was estimated. The relative proportion of each vegetation
14 type found in each topographic category in a region was approximated based on field experience
15 (Mohler, pers. obs.) and the relative frequency of the types in the sample data. The area in each
16 vegetation type was then computed by multiplying the area of each topographic category by the
17 proportion of that category in each vegetation type, and then summing over topographic
18 categories. Relative area in the various types ranged from 0.02% to 64%. The resulting area
19 estimates were approximate, but were sufficient for assessing error rates.

20 21 Database Design and Development

22 Existing databases were compiled and integrated using established geographic information
23 processing methods (Burrough 1986, ERDAS 1991) to provide environmental data of the sort
24 used in the vegetation classification scheme. The spatial resolution of the database was defined
25 using grid cells representing a ground surface dimension of 100m x 100m and geo-referenced to
26 the Universal Transverse Mercator projection and coordinate system (Snyder, 1982). A state-
27 level soil geographic database (STATSGO) provided groupings of soils into map units. For the
28 study area, there were 46 soil map units each comprised of 20 or more components consisting of
29 soil series phased by slope gradient class. Map units had a minimum size delineation of 625
30 hectares.

31
32 The STATSGO database was used to estimate soil parent material, drainage, acidity, and
33 slope position for each grid cell. Interpretation of soil parent material for each map unit was
34 derived from the STATSGO legend, and pedon descriptions for the components of each map unit.
35 Seven parent material classes were defined: deep glacial till without restrictive layer (e.g.
36 fragipan), deep glacial till with restrictive layer, moderately-deep to shallow glacial till, lacustrine
37 sediments, glacial outwash deposits, alluvium, and organics.

38
39 For the remaining five environmental variables, break points were chosen in the
40 continuous or categorical gradients which field experience (Mohler, per. obs.) indicated would
41 maximize differences in forest composition between contrasting categories. Database
42 programming scripts were used to compute average soil pH and frequency distribution of soil
43 drainage for each map unit. Soil acidity for each map unit was computed as an area-weighted
44 average by using the mid-point of pH range published for each map unit component. Based on
45 the computed map unit average pH, each map unit was classified as "acid" ($\text{pH} < 6.1$), or "non-

acid" ($\text{pH} \geq 6.1$). Soil drainage for each map unit was determined by computing the frequency distribution of drainage classes based on the percent occurrence of soil map unit components. If a majority of the drainage classes occurring in a map unit was estimated to be very poorly or poorly drained soil, soil drainage for the map unit was classified as "poor". If a majority of the drainage classes were somewhat poorly drained or better the map unit was classified as "well". Slope position for each map unit was interpreted into three classes using the catena concept for characterizing and mapping soil landscapes in New York State (Cline and Marshall 1977): lower (toe- and foot-slopes), middle (backslopes), and upper (shoulder- and summit-slopes). Nomenclature follows Wilding et. al. (1983). Since slope position is generally correlated with soil drainage, soil components in each map unit were assigned a slope position class based on their drainage class. Soil components that were excessively well-drained or well-drained were assigned to the "upper" slope position. Soil components that were moderately-well drained were assigned the "middle" slope position, and those components that were somewhat-poorly, poorly, or very poorly drained were assigned to the "lower" slope position. The map unit was assigned a slope position class based on the majority slope position class occurring in the map unit on an area percentage basis. Soil parent material class for each map unit component was determined by reviewing the official soil series description and assigning a parent material class to the map unit based on the majority parent material occurring in the unit.

Slope gradient and slope azimuth were estimated from the Elmira 1:250,000 scale digital terrain data (U.S. Geological Survey 1987). Slope gradient classes were computed using finite differencing techniques (ERDAS, Inc. 1991) in one percent increments and then aggregated into three ranges: nearly level (0-4%), gently sloping (5-15%), and steeply sloping (>15%). Slope azimuth was computed in one-degree increments and then aggregated into three aspect classes: north (293-112°), and south (113-292°) as well as flat. The 22° clockwise rotation was included in the definition of the aspect classes because vegetation on east facing slopes resembles that on north facing slopes more than does the vegetation on west slopes.

Decision-Tree Model

A decision-tree model was developed to integrate the vegetation classification with the geographic database of the soil and terrain factors (Figure 1). First, the digital soil map was overlain with the digital map of terrain variables to derive a 414-class map of soil-terrain relationships. Next, each soil-terrain class was related to plant community types to form the decision-tree model.

Given the categorical and mapping detail at which soil and terrain data were available in the geographic database (Table 1), not all 17 vegetation types could be discriminated. The original vegetation classification scheme was aggregated into 10 generalized vegetation groups, each of which included several types which are commonly found adjacent to one another, intergrade, or occupy similar habitats. Because some of the more common vegetation types occur in a broad range of conditions but with varying frequency, they were included in more than one of the vegetation groups predicted by the decision tree model.

Error Assessment Methodology

1 We assessed two possible sources of error: error in the input variables to our decision
2 tree model and error in the actual prediction. For each of the six decision tree variables, we
3 examined the agreement between the GIS-derived estimates of these six variables and direct field
4 observations by cross-classifying the GIS data versus field data. The proportion of plots that fell
5 along the main diagonal of such a cross-classification measures the overall agreement since it
6 gives the number which were classified the same. Cohen's kappa (Cohen, 1960) measures
7 agreement adjusted for chance on a scale where zero indicates no agreement and one indicates
8 total agreement. Kappa equals zero when the estimates and field data are statistically independent
9 (i.e., when the probability of agreement is equal to the product of the marginal probabilities). To
10 estimate the agreement under independence, the observed marginal probabilities are typically
11 used; in some sampling schemes these are not valid estimates of the true marginal probabilities
12 and alternate measures of agreement should be used (Aickin, 1990; Brennan and Prediger, 1981).
13 The preceding comparisons focus on a single variable at a time and ignore the associations that
14 may exist between variables. Therefore, as an multivariate extension of examining agreement, we
15 calculated how often disagreements in one variable occur in conjunction with another variable.
16 This shows which pairs of variables tend to be poorly approximated by the GIS data.

17
18 We also used the kappa coefficient to summarize agreement between vegetation
19 distributions predicted using GIS-derived estimates and using field observations. For many uses it
20 will be possible to specify or approximate the cost of misclassification by the model and, since
21 certain misclassifications will have higher costs than others, it will lead to a more appropriate
22 assessment of model performance. A matrix of misclassification costs was constructed (Table 2)
23 based on the degree of compositional similarity of the types composing pairs of vegetation
24 groups. Pairs which differed primarily in the relative proportion of their component vegetation
25 types were given low misclassification costs (values of 1 to 3). In contrast, a pair received a
26 maximum value of 10 if their predominant vegetation types were characteristic of sites differing in
27 both drainage and soil pH (e.g., poorly drained and calcareous versus well drained and acid).
28 Intermediate situations received intermediate misclassification costs, but a minimum cost of 8 was
29 assigned to all pairs in which one was composed of types characteristic of uplands whereas the
30 other was made up of wetland types. Average cost estimates must be referred to the above
31 definitions for interpretation. Costs can be specified according to other criteria.

32
33 To estimate the expected cost of misclassification a table cross classifying vegetation
34 groups predicted using field and GIS data was first prepared. The proportion of occurrence of
35 each entry was then multiplied by its corresponding cost according to Table 1 and the product
36 summed over all entries. This value was then compared with the expected cost of
37 misclassification under statistical independence. This is equivalent to calculating a weighted
38 kappa (see Fleiss, 1981, p.223), where $\text{weight} = 1 - \text{cost}/10$.

39
40 To investigate the effect of each decision tree variable on misclassification, the field data
41 were replaced with GIS data one variable at a time, resulting in six transformed data sets. The
42 model predictions obtained from these data sets were then compared with those obtained using
43 only field data. This is similar to a sensitivity analysis, where one variable is varied while all other
44 variables are kept constant. The six transformed data sets differ from the field data by only one
45 variable. When the GIS estimate of the variable is the same as the field measurement, the same

1 prediction necessarily results. However, when the GIS estimate of the variable is different from
2 the field estimate, the transformed data and the field data can still have the same prediction since
3 different combinations of input values may produce the same prediction. The more often this
4 happens, the more robust is the model to misclassifications in that variable. Likewise, we define
5 robustness as the proportion of plots with identical predictions among those with different
6 variable input.

7
8 Finally, to assess the misclassification rate of the decision tree model, we compared the
9 predicted vegetation groups with the actual field vegetation types. This was done with the field
10 data as input and also with the GIS data as input. The former evaluates the pure prediction error
11 of the decision tree model (assuming accuracy of the field data), whereas the latter includes the
12 error involved in using the, sometimes inaccurate, GIS data as input. Overall misclassification
13 rates were taken to be the total proportion of misclassified plots. Also, to estimate the
14 misclassification rate for a randomly selected plot in the study area, weighted misclassification
15 rates were calculated by multiplying the proportion of misclassified plots in each field vegetation
16 type by the estimated proportion of that vegetation type occurring in the study area, and then
17 summing these products over all the vegetation types.

18 19 **RESULTS AND DISCUSSION**

20 21 Error Analysis of Input Variables

22 There was moderate data agreement between GIS and field data for acidity but poor
23 agreement for drainage (Table 3). Note that use of the proportion of plots with identical
24 classification as the sole measure of agreement can give misleading conclusions as exemplified for
25 the drainage variable. This indicates the importance of using several indices to measure
26 agreement, and knowing when a particular index would yield valid inferences. Slope gradient and
27 slope aspect had the highest frequency of joint misclassification (Table 3). This correlation is a
28 reflection of the poor resolution of the digital elevation map, from which the gradient and aspect
29 were calculated. On the other hand, there does not seem to be a clear physical explanation for
30 why high frequencies of misclassification in parent material and slope position occur together with
31 slope gradient.

32
33 The imprecision of the soils and digital elevation databases used in the study contributed
34 to a relative lack of agreement between field and GIS data (Table 1). The imprecision resulted
35 from both the coarse scale of the GIS data and inaccuracy in determining location of grid cells.
36 The state-level soil survey data (Soil Conservation Service, 1991) were derived by generalizing
37 soil information contained in detailed soil surveys. This aggregation created map units with highly
38 heterogeneous soil composition, without adequate reference as to where the aggregated
39 component-units were located spatially. Consequently, important soil conditions which occur in
40 relatively small patches were not adequately represented in the GIS data. Similarly, although
41 slope gradient and aspect were computed for each 100 m x 100 m grid cell, the digital elevation
42 model integrated over much larger areas when calculating the estimated values. In contrast, slope
43 and azimuth measurements taken in the field were only intended to characterize a small plot and
44 therefore frequently differed from the average slope and aspect of the larger area. Finally, slope
45 positions were approximated using the assumed slope position of the dominant soil series in its

catena. This resulted in large landscape units being assigned a slope position which often was at variance with the slope position characterized at a given field plot. Thus, the accuracy assessment of environmental databases of such coarse categorical and cartographic resolution using highly detailed field plot data of limited spatial extent is problematic.

Although our use of spatial databases was reasonable given the constraints associated with their lack of detail, we consider these regional scale databases currently inadequate for predicting the distribution of potential vegetation types at landscape scale which meets the expectations of field ecologists.

Error Analysis of Model Predictions

Poor agreement between GIS and field data input variables does not necessarily cause incorrect prediction of the decision tree model since different combinations of values in the input variables may still give the same predicted vegetation. Summing the diagonal entries in Table 5, we found 98 plots (35.5%) had identical predicted vegetation groups, and the kappa coefficient was 0.252. Hence, if the decision tree model gave perfect predictions, we would still expect a minimum misclassification rate of 65% when using GIS estimates because of errors in the input data. Based on the cost matrix, the expected cost of misclassification was 2.55, compared with 3.49 if we assume an independence structure. Twenty percent of the plots had costs greater than five. As in a residual analysis, closer examination of individual entries with large number of misclassifications in Table 5 may help identify weaknesses in the decision tree model. The two entries with the highest misclassifications received costs not greater than two, which illustrates why adjusting for misclassification costs in this case decreases the severity of misclassification.

Environmental variables differed in their effect on predictions of vegetation type by the decision tree model (Table 6). The model had low robustness with respect to acidity, aspect and drainage. Acidity and aspect had high agreement and thus may not be critical in causing misclassification. On the other hand, drainage had low agreement as indicated by its kappa statistic (Table 3), which makes it more critical to the decision tree. Similarly, slope gradient had fair agreement and robustness, which may cause a substantial amount of prediction error. Therefore, by combining results on agreement and robustness, we can assess the strength of input variables on the decision tree model, which was not possible by simply looking at data agreement between GIS and field data (Table 3) or just by comparing the predicted outcomes using the two types of input (Table 5).

Cross-classification of field vegetation types versus predicted vegetation groups shows an overall misclassification rate of 0.233 (64/275) using field data (Table 7a). Thus, even with perfect input, the decision tree model has only 77% accuracy in predicting vegetation at the field sample plots. This error results from several factors. First, it is presumptuous to expect our six selected environmental variables to perfectly predict vegetation. Second, all of the field sample plots have experienced human disturbance, which in some cases may have shifted the composition away from that expected from environmental influences alone. Third, since bogs, cliffs, and narrow ravines were of too limited spatial extent to be characterized by coarse scaled digital elevation and soils databases, the vegetation types corresponding to these landscape units were omitted from the decision tree, or had to be incorporated as inclusions within a more broadly

1 defined vegetation group. Moreover, since plots and samples were selected in a way which
2 favored rare and unusual types of vegetation, these environments were disproportionately
3 represented in the field data relative to their area in the landscape. When the cross classification
4 was weighted by the relative area of the field vegetation types, the misclassification rate dropped
5 to a much lower 6.4%. This is because the two dominant field types G and H, which occupy 90%
6 of the study area, had misclassification rates of 6% or less. Moreover, this weighted
7 misclassification rate suggests that the probability of misclassification given field data for a
8 randomly chosen plot would be rather small.

9
10 Using the GIS databases as inputs to the decision tree gave an overall misclassification
11 rate of 0.451 (124/275) (Table 7b). This represents the compounding of imprecision in the
12 databases and the problems with the decision tree discussed above. Again, the problems tended
13 to be most prevalent with relatively uncommon vegetation types which occurred in environmental
14 conditions of limited extent. Consequently, when the cross classification of field vegetation types
15 and vegetation groups was weighted by the relative area of the field types, the misclassification
16 rate dropped to 5.9%. This value was comparable to the weighted misclassification rate based on
17 field data, and indicated that a map produced from model predictions would be basically correct
18 as a general description of the vegetation in the study area. Field sampling near the western edge
19 of the Elmira quadrangle, however, indicates that the model would have a much higher
20 misclassification rate in that area (Mohler, per. obs.). This is a good warning as to the dangers of
21 extrapolating beyond the region in which data were gathered to construct the model. Moreover,
22 the absence of important details, like wetlands in the southern region, limit the usefulness of the
23 model.

24 25 CONCLUSIONS

26
27 We have demonstrated methods for assessing errors which propagate through decision
28 tree models and for incorporating differing costs of classification errors. These methods allowed
29 us to measure misclassification due to (1) accuracy of input data and (2) sensitivity of model
30 predictions to input data. We characterized these two components as accuracy and robustness.

31
32 When these methods were applied to predict the distribution of potential forest vegetation
33 in central New York State, we found that the quality of the input data was rather low. This did
34 not necessarily cause errors in the decision tree model predictions, since predictions were found to
35 be sensitive to changes only in some input variables.

36
37 The main source of error in the model appears to be the coarse scale of the spatial
38 databases which served as input to the decision tree model. First, since the data were imprecise,
39 they often failed to reflect the true environmental parameter values as measured at field locations.
40 Second, the coarse scale of the databases constrained the structure of the decision tree such that it
41 sometimes did not function well even when data from the field were used. We are currently
42 investigating the effects of data scale on GIS decision tree models.

43
44 Our experience in developing error assessment methods also revealed the need for prudent
45 field sampling methods for model verification. Common methods of analysis (e.g., Cohen's

1 kappa) depend on the structure of the sampling scheme (i.e., they may not be valid with
2 something other than a simple random sample). Care must be taken to match the scale of model
3 predictions with field samples for their verification (Rastetter et al, 1992). Sampling must be
4 representative of the spatial area to which the model will be applied; otherwise the model may
5 unknowingly fail when applied to a new area. Samples should be selected to test each component
6 of the model. This last point argues that model information like the scale and resolution of the
7 input data are necessary before an intelligently chosen verification sample can be selected.

8
9 Advances are needed in integrating environmental data and predictive models in order to
10 improve our understanding of vegetation distributions at landscape scale. Based on this improved
11 understanding, resource inventory and spatial databases can be designed to incorporate critical
12 environmental variables reflective of processes influencing distributions. Finally, software must be
13 developed to enable these models to be used in the policy and decision making processes of
14 environmental organizations.

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REFERENCES

- Aicken, M. 1990. Maximum likelihood estimation of agreement in the constant predictive probability model and its relation to Cohen's kappa. *Biometrics* **46**: 293-302.
- Brennan, R.L. and Prediger, D.J. 1981. Coefficient kappa: some uses, misuses and alternatives. *Ed. and Psych. Meas.* **41**: 687-699.
- Burrough, P.A. 1986. Principles of geographical information systems for land resources assessment. Clarendon Press, Oxford. 194p.
- Cline, M.G. and R.L. Marshall. 1977. Soils of New York Landscapes. Information Bulletin #119. Cornell Cooperative Extension. Cornell University. Ithaca, New York. 62p.
- Cohen, J. 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement* **20**:37-46.
- ERDAS, Inc. 1991. Field Guide, Version 7.5. ERDAS, Inc. Atlanta, Georgia.
- Fleiss, J. 1981. Statistical Methods for Rates and Proportions. New York: John Wiley & Sons, Inc. 321p.
- Gardner, R.H., D.D. Huff, R.V. O'Neill, J.B. Mankin, J. Carney, and J. Jones 1980. Applications of error analysis to a marsh hydrology model. *Water Resources Research* **16**(4):659-664.
- Goodchild, M. and S. Gopal. 1989. Accuracy of Spatial Databases. New York: Taylor & Francis. 290p.
- Goodchild, M., S. Guoqing and Y. Shiren. 1992. Development and test of an error model for categorical data. *Int. J. Geographical Information Systems* **6**(2):87-104.
- Heuvelink, G.B.M. 1993. Error propagation in quantitative spatial modelling: Applications in geographical information systems. Netherlands Geographic Studies #163. Univ. Utrecht, the Netherlands, 295 pp.
- Hill, M.O., R.G.H. Bunce, and M.W. Shaw 1975. Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. *J. Ecol.* **63**:597-613.
- Huenneke, L.E. 1982. Wetland forests of Tompkins County, New York. *Bull. Torrey Bot. Club* **109**:51-63.
- Hutton, F.Z., Jr. 1971. Soil survey of Cayuga County, New York. USDA Soil Conservation Service. U.S. Govt. Printing Office. Washington, D.C. 205 p.

- Hutton, F.Z., Jr. 1972. Soil survey of Seneca County, New York. USDA Soil Conservation Service. U.S. Govt. Printing Office. Washington, DC. 143 p.
- Lewin, D.C. 1974. The vegetation of the ravines of the southern Finger Lakes, New York, region. *Am. Midl. Nat.* **91**:315-342.
- Marks, P.L. and S. Gardescu. 1992. Vegetation of the central Finger Lakes Region of New York in 1790s. *New York State Museum Bulletin #484* 1-35. Albany, New York.
- Mohler, C.L. 1991. Plant community types of the central Finger Lakes Region of New York: A synopsis and key. *Proc. Rochester Acad. Sci.* **17**(2):55-103.
- Mohler, C.L. and P.L. Marks. Vegetation-environment relations in the central Finger Lakes Region of New York. (In Preparation).
- Moore, D.M., B.G. Lees and S.M. Davey. 1991. A new method for predicting vegetation distributions using decision tree analysis in a geographic information system. *Environmental Management* **15**:59-71.
- Neeley, J.A. 1965. Soil survey of Tompkins County, New York. USDA Soil Conservation Service. U.S. Govt. Printing Office, Washington, DC. 241p.
- O'Neill, R.V. 1973. Error analysis of ecological models. In *Radionuclides in Ecosystems*, pp. 898-908. D.J. Nelson, Ed. CONF-710501. National Technical Information Service, Springfield, Virginia, U.S.A.
- Puglia, P.S. 1979. Soil survey of Schuyler County, New York. USDA Soil Conservation Service. U.S. Printing Office. Washington, DC. 192p.
- Rastetter, E.B., A.W. King, B.J. Cosby, G.M. Hornberger, R.V. O'Neill, and J.E. Hobbie 1992. Aggregating fine-scale ecological knowledge to model coarser-scale attributes of ecosystems. *Ecological Applications* **2**(1):55-70.
- Reybold, W.U. and G.W. TeSelle. 1989. Soil geographic databases. *J. Soil and Water Cons.* **44**:28-29.
- Rossi, R.E., P.W. Borth, and J.J. Tollefson 1993. Stochastic simulation for characterizing ecological spatial patterns and appraising risk. *Ecological Applications* **3**(4):719-735.
- Saltelli, A., T.H. Andres, and T. Homma 1993. Sensitivity analysis of model output: an investigation of new techniques. *Computational Statistics & Data Analysis* **15**:211-238.
- Seischab, F.K. 1985. An analysis of the forests of the Bristol Hills of New York. *Am. Midl. Nat.* **114**:77-83.

Seischab, F.K. 1990. Presettlement forests of the Phelps and Gorham Purchase in western New York. *Bull. Torrey Bot. Club* **117**:27-38.

Smith, B.E., Marks P.L., and S. Gardescu. 1993. Two hundred years of forest cover changes in Tompkins County, New York. *Bull. Torrey Botanical Club*. **120**:229-247.

Snyder, J.P., 1982. Map projections used by the U.S. Geological Survey. *Geol. Survey Bulletin* #1532. U.S. Government Printing Office, Washington, D.C.

Soil Conservation Service. 1991. State Soil Geographic Data Base (STATSGO). Misc. Publ. #1492. U.S. Dept. Agriculture. Washington, DC. 88p.

Soil Conservation Service. 1981. Land resource regions and major land resource areas of the United States. USDA Soil Conservation Service Agric. Handbook #296. Washington, DC. 156p.

U.S. Geological Survey. 1987. Digital Elevation Models. Data Users' Guide #5. U.S. Geological Survey. Reston, Virginia. 38p.

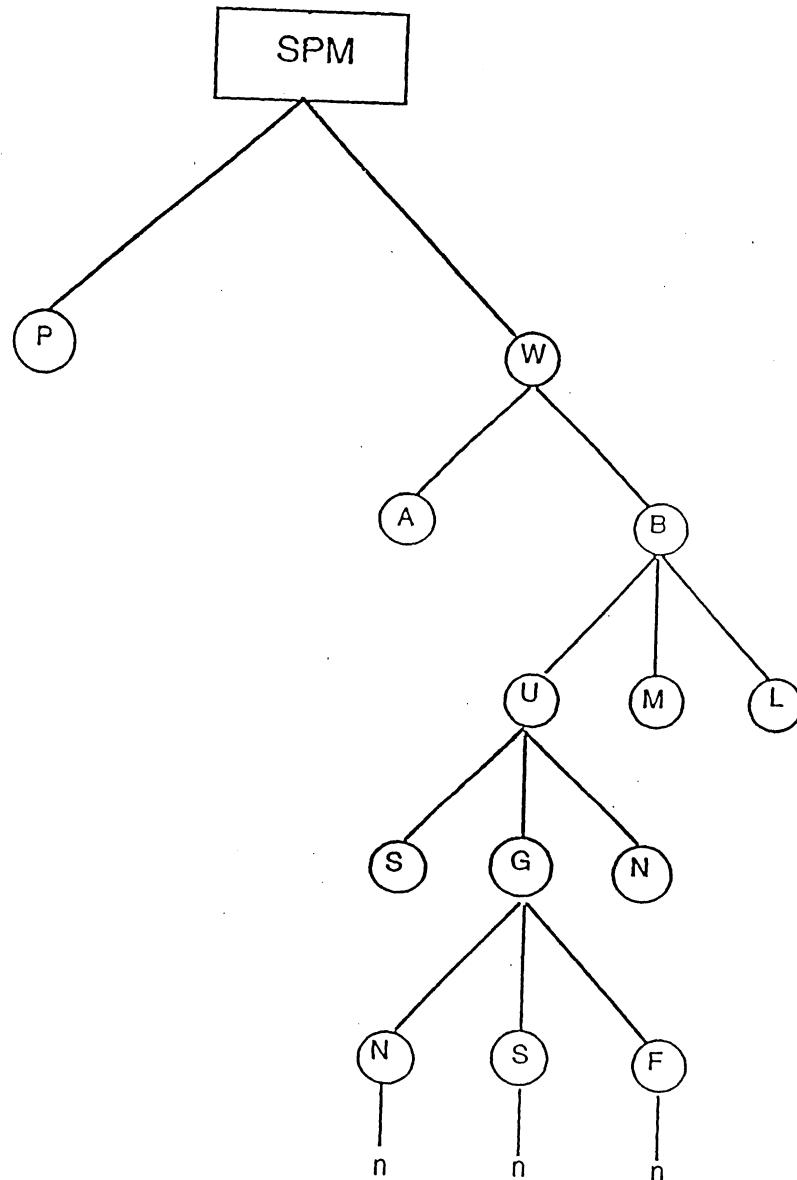
Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecol. Monogr.* **30** 279-338.

Wilding, L.P., N.E. Smeck, and G.F. Hall (ed.) 1983. Pedogenesis and soil taxonomy. I. Concepts and interactions. Elsevier, New York.

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Figure 1: A schematic of the decision-tree model for a single soil parent material (SPM). The model was used to predict the distribution of potential vegetation.



Soil Parent Material (SPM)

DGT0 = glacial till, deep
 DGT1 = glacial till, fragipan
 MSGT = glacial till, mod. deep, shallow
 LCST = lacustrine
 OUTW = glacial outwash
 ALVM = alluvium
 ORGN = organics

Soil Drainage

P = poor (P, VP)
 W = well (SP, MW, W, SE, E)

Soil Acidity

A = acid (pH<6.1)
 B = non-acid (pH 6.1+)

Slope Position

L = lower
 M = middle
 U = upper

Slope Gradient

N = nearly level (0-2%)
 G = gently sloping (3-15%)
 S = steeply sloping (> 15%)

Slope Aspect

N = north (293-112°)
 S = south (113-292°)
 F = flat

Vegetation Type

n

Table 1. Characteristics of environmental databases and field survey data

	Variable	Source	Scale	Minimum Size Delineation	Units	
					(in data)	(in model)
GIS	Parent Material	Soil Conservation Services	1:250,000	Choropleth (625 ha)	7 classes	7 classes
	Drainage				5 classes	2 classes
	Acidity				5 classes	2 classes
	Slope Position				5 classes	3 classes
	Aspect	Geological Survey	1:250,000 (1 ha pixel)	20 m Contours	degrees	3 classes
	Gradient				percent	3 classes
FIELD	Vegetation	Mohler & Marks ²	0.1 ha plot	0.1 ha	17 classes	10 classes
	Parent Material	Soil Survey ¹	1:15,840	Choropleth (0.405 ha)	7 classes	7 classes
	Drainage				5 classes	2 classes
	Acidity				5 classes	2 classes
	Slope Position				5 classes	3 classes
	Aspect	Mohler & Marks	0.1 ha plot	0.1 ha	degrees	3 classes
	Gradient				percent	3 classes

¹soil surveys from Neeley, 1965, Hutton, 1971 & 1972, Puglia, 1979

²Mohler & Marks, in preparation

Table 2. Costs associated with the misclassification of vegetation groups.
(0 equals no cost, and 10 equals maximum cost.)

		VEGETATION GROUPS									
		1	2	3	4	5	6	7	8	9	10
V	1	0	2	8	9	10	8	8	10	8	9
E	2		0	8	9	10	7	7	9	8	10
G	3			0	2	4	1	3	4	2	3
.	4				0	2	3	3	2	3	1
G	5					0	5	5	3	5	3
R	6						0	1	2	1	4
O	7							0	2	2	3
U	8								0	2	2
P	9									0	3
S	10										0

Table 3. Agreement between GIS input and field input for the six decision tree variables

Input Variable	Proportion with same classification	Cohen's Kappa
Parent material	.424	.303
Drainage	.786	.073
Acidity	.797	.592
Slope Position	.417	.159
Slope Gradient	.515	.267
Slope Aspect	.649	.456

Table 4. Frequency of joint misclassification among the six decision tree variables

	Drainage	Acidity	Position	Gradient	Aspect
Parent Material	43	46	86	86	64
Drainage		15	25	10	10
Acidity			30	30	30
Position				75	55
Gradient					90

Table 5. Cross-classification of vegetation groups predicted using GIS input and using field input. Diagonal entries (in bold) sum to 98 (35.5%) and show the frequency that the two input sources shared the same predicted classification.

		GIS									
		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
F I E L D	F1	0	0	0	7	0	1	0	0	6	0
	F2	0	8	2	6	0	3	14	0	15	0
	F3	0	0	10	4	0	1	0	0	0	0
	F4	0	1	17	34	2	2	3	0	3	0
	F5	0	0	2	2	6	0	2	0	0	0
	F6	0	0	0	11	0	8	22	0	3	0
	F7	0	0	0	2	0	2	21	0	0	0
	F8	0	0	1	1	0	2	4	1	2	0
	F9	0	1	7	9	0	3	8	1	10	0
	F10	0	0	1	2	0	1	1	0	1	0

Table 6. Robustness of input variables in the decision tree model.

Variable Replaced	No. w/ same Prediction	Robustness
Parent Material	219	.642 (102/159)
Drainage	218	.017 (1/59)
Acidity	224	.071 (4/56)
Slope Position	216	.627 (101/161)
Gradient	182	.299 (40/134)
Aspect	186	.072 (7/97)

Predictions using field data for all six decision tree input variables are compared with the predictions using GIS estimates for one of the input variables but field data for the other five variables. The first column gives the number of plots with the same predictions when the GIS variables were used for each of the decision tree input variables. Robustness is the proportion of plots which have identical predictions among those with different variable values.

Table 7a. Cross-classification table of field vegetation types versus predicted map vegetation groups using field observations as input. r_i =row total, c_i =column total, m_i =number of misclassified plots, and w_i =percent of field vegetation type in study area. Table entries in bold denote possible matches. Field vegetation type Q is a combination of four subtypes and only one of the four denotes a possible match.

		PREDICTED MAP VEGETATION GROUP (using FIELD input)										r_i	m_i	w_i
		1	2	3	4	5	6	7	8	9	10			
FIELD VEGETATION TYPE	A	0	0	1	3	6	0	0	0	0	0	10	4	0.20
	B	0	0	0	21	2	3	1	2	2	2	33	4	3.00
	C	0	0	0	1	1	3	1	3	0	0	9	6	0.20
	D	0	0	0	0	0	1	0	4	0	0	5	5	0.02
	E	0	0	4	2	0	5	5	0	3	0	19	6	2.00
	F	0	0	0	0	0	0	0	0	1	1	2	1	0.05
	G	0	1	2	11	2	14	10	0	10	0	50	3	63.9
	H	0	0	6	14	1	6	6	0	6	2	41	1	27.0
	I	1	0	2	6	0	10	0	1	13	1	34	11	0.50
	J	1	1	0	4	0	1	0	1	4	0	12	12	0.25
FIELD VEGETATION TYPE	K	0	0	0	0	0	1	0	0	0	0	1	1	0.06
	L	4	7	0	0	0	0	0	0	0	0	11	0	0.40
	M	2	18	0	0	0	0	2	0	0	0	22	2	1.70
	N	0	4	0	0	0	0	0	0	0	0	4	0	0.30
	O	0	9	0	0	0	0	0	0	0	0	9	0	0.10
	P	0	3	0	0	0	0	0	0	0	0	3	0	0.05
	Q	6	4	0	0	0	0	0	0	0	0	10	8	0.02
c_i		14	47	15	62	12	44	25	11	39	6	275	64	

Table 7b. Cross-classification table of field vegetation types versus predicted map vegetation groups using GIS estimates as input.

		PREDICTED MAP VEGETATION GROUP (using GIS input)										r_i	m_i	w_i
		1	2	3	4	5	6	7	8	9	10			
FIELD VEGETATION TYPE	A	0	0	3	4	3	0	0	0	0	0	10	7	0.20
	B	0	1	7	16	1	1	6	0	1	0	33	8	3.00
	C	0	0	0	0	2	1	6	0	0	0	9	9	0.20
	D	0	0	1	0	0	1	1	1	1	0	5	5	0.02
	E	0	1	3	4	0	1	9	0	1	0	19	7	2.00
	F	0	0	0	0	0	0	0	1	1	0	2	2	0.05
	G	0	0	5	14	1	6	20	0	4	0	50	1	63.9
	H	0	0	12	16	0	2	9	0	2	0	41	0	27.0
	I	0	0	5	9	0	6	7	0	7	0	34	21	0.50
	J	0	0	3	4	1	0	2	0	2	0	12	12	0.25
	K	0	0	0	0	0	1	0	0	0	0	1	1	0.06
	L	0	0	0	5	0	1	1	0	4	0	11	11	0.40
	M	0	4	0	3	0	0	12	0	3	0	22	18	1.70
	N	0	2	0	0	0	0	1	0	1	0	4	2	0.30
	O	0	2	1	1	0	3	0	0	2	0	9	7	0.10
	P	0	0	0	1	0	0	0	0	2	0	3	3	0.05
	Q	0	0	0	1	0	0	1	0	8	0	10	10	0.02
c_i		0	10	40	78	8	23	75	2	39	0	275	124	